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Submarine slides north of Puerto Rico and their tsunami potential

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Newly-acquired multibeam bathymetry of the entire Puerto Rico trench sheds new light on tsunami hazards for the north coast of Puerto Rico and allows us to construct more realistic tsunami runup models. The Puerto Rico trench, the deepest part of the Atlantic Ocean, is located along where the plate boundary of the North American tectonic plate (NOAM) is subducted under the Caribbean plate, producing frequent earthquakes. A 60-km wide region between the trench and Puerto Rico is unusually deep (up to 7900 m) and is associated with the most negative free-air gravity anomaly on Earth. A 4000-meter-high slope separates the deep forearc region from a gently-tilted carbonate platform that extends southward from a depth of 3500-4000 m to the northern shore of Puerto Rico. The carbonate platform was tilted about 3.5 m.y. ago toward the trench during an estimated time period of 26-725 k.y. [ten Brink et al., in prep.].

Subsidence of the trench and the tilt of the carbonate platform were probably accompanied by slope failures. For example, a large escarpment was identified at the edge of the carbonate platform 37 km north of Arecibo, Puerto Rico [*Mercado et al.*, 2002; *Scanlon and Masson*, 1996; *Schwab et al.*, 1991]. The amphitheater-shaped slide scar was postulated to have formed by giant submarine slope failure with a displaced volume of over 910-1500 km^3 (Schwab et al., 1991; Mercado et al., 2002). Maximum runup of 30-55 m was calculated from this failure, with a runup >10 m along the entire northern coast of Puerto Rico [*Mercado et al.*, 2002].

The new multibeam bathymetry data and associated backscatter mosaics show two large amphitheater-shaped headwall scarps at the edge of the carbonate platform, the Arecibo amphitheater, which is 50-km across, and the Loiza amphitheater, which is 30-km across. Several smaller scarps and slopee failures were also identified all along the edge of the carbonate platform. The data suggest that the amphitheaters were probably not the result of single catastrophic slides, but were shaped by continuous retrograde slumping of smaller segments. The debris fields from slumps in the Loiza amphitheater extend downslope as much as 40 km from the scarp. They are up to 200 m thick and have distinct toes. In contrast, the debris from one of the large failures in the Arecibo Theater appears to be perched on the slope less than 5 km from the scarp's head. Debris flow deposits cannot be identified in the bathymetry data for the other failures in this amphitheater. Backscatter images show distinct highly reflective bands, that perhaps represent deposits with thicknesses that are less than the vertical resolution of the bathymetry data. Several-hundreds-meter wide cracks were discovered near the edge of the carbonate platform at the head of these amphitheaters. For example, a 15 km-long crack is located 1-3 km back from the edge of the Loiza Amphitheater, and a 7x3 km subsided area at the

edge of the Arecibo amphitheater is surrounded by cracks. The presence of cracks indicates that the slumping process is on going, and may constitute future tsunami hazard.

Slumps are not limited to the carbonate platform. Several submarine slide scarps and slide toes were observed for the first time on the northern trench wall, where the North America plate drops into the trench by 2-2.5 km over a distance of 20-25 km. The largest scarp, located at a depth of 6500 m is 20 km wide, 1500 m high and is associated by a 400 m high curved toe 15 km in front of the scarp. The areas to the north and the west of that scarp, including what appears to be an excavated side of a seamount may also be associated with submarine slope failures. Slopes reaching 45° and vertical offsets of up to 8 km were also observed near Navidad Bank and Mona Block, and along fault scarps on the descending NOAM plate NE of the Virgin Islands. These conditions may generate submarine slope failures. Slope failures on the northern wall of the trench should be evaluated for tsunami potential because the direction of slide movement and therefore the directivity of slide-generated waves are toward Puerto Rico.

The cohesiveness of the sliding material plays an important role in the time evolution and terminal speed of slides, and therefore in the expected tsunami wave height. Unlike failures and slides in many other continental margins, slumps in the Puerto Rico trench are for the most part expected to be quite cohesive. The edge of the carbonate platform likely comprises a 1-1.5 km thick layer of highly massive or layered limestone, with some shaly sand layers toward the bottom of the section [*Monroe*, 1980; *van Gestel et al.*, 1999]. The carbonate platform is probably underlain by volcanoclastic, volcanic, and igneous rocks of the arc and forearc, which may be less cohesive during failure. Slumps off Navidad Bank, Mona Bank, and the walls of Mona rift are likely made of cohesive limestone. Slumps on the NOAM plate are likely to comprise about 0.5-1 km of pelagic sediment and chert layers underlain by upper oceanic crust basalts.

Preliminary source and hydrodynamic modeling based on the landslide geometry of one of the failures in the Arecibo Amphitheater was performed to determine the magnitude of runup heights on shore. As indicated in the results of *Mercado et al.* [2002] the value used for the process time parameter has a significant effect on nearshore runup heights. The hydrodynamic simulation was performed using the weakly-nonlinear "extended" wave equations (WNL-EXT) in the COULWAVE model developed by *Lynett and Liu* [2002]. Initial results for a slide identified in the Arecibo amphitheater indicate that runup broadside from the source is on the order of 20 m, using a process time of 200 s. This process time is smaller than the smallest value used for the Arecibo slide (1000 s) in *Mercado et al.* [2002] for a much larger slide (910 km3) in the Arecibo amphitheater. It is reasonable to assume that the process time scales with the size of the slide. Further work will determine runup heights based on other identified features and variable process times.

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